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ABSTRACT Cities are blamed for the majority of greenhouse gas (GHG) emissions. So too are more affluent, highly urbanized countries. If all production- and consumption-based emissions that result from lifestyle and purchasing habits are included, urban residents and their associated affluence likely account for more than 80 per cent of the world's GHG emissions. Attribution of GHG emissions should be refined. Apportioning responsibility can be misguided, as recent literature demonstrates that residents of denser city centres can emit half the GHG emissions of their suburban neighbours. It also fails to capture the enormous disparities within and across cities as emissions are lowest for poor cities and particularly low for the urban poor.

This paper presents a detailed analysis of per capita GHG emissions for several large cities and a review of per capita emissions for 100 cities for which peer-reviewed studies are available. This highlights how average per capita GHG emissions for cities vary from more than 15 tonnes of carbon dioxide equivalent (tCO2e) (Sydney, Calgary, Stuttgart and several major US cities) to less than half a tonne (various cities in Nepal, India and Bangladesh). The paper discusses where GHG emissions arise and where mitigation efforts may be most effective. It illustrates the need to obtain comparable estimates at city level and the importance of defining the scope of the analysis. Emissions for Toronto are presented at a neighbourhood level, city core level and metropolitan area level, and these are compared with provincial and national per capita totals. This shows that GHG emissions can vary noticeably for the same resident of a city or country depending on whether these are production- or consumption-based values. The methodologies and results presented form important inputs for policy development across urban sectors. The paper highlights the benefits and drawbacks of apportioning GHG emissions (and solid waste generation) per person. A strong correlation between high rates of GHG emissions and solid waste generation is presented. Policies that address both in concert may be more effective as they are both largely by-products of lifestyles.

KEYWORDS cities / climate change / scope of emissions / urban GHG emissions / urban policy complementarities

I. CITIES AND CLIMATE CHANGE

Climate change and urbanization are two of the most important phenomena facing the world today; and they are inextricably linked. Poverty reduction and sustainable development remain as core global priorities but, as the *World Development Report 2010* emphasizes, climate change now threatens to undermine the progress achieved by

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low- and middle-income countries, and the poorest populations are most vulnerable.[1]

The *World Development Report 2009* presented a new development paradigm: harnessing the growth and development benefits of urbanization while proactively managing its negative effects.[2] Urbanization likely presents the best chance for the world's poorest, however up to now most GHG emissions (and solid waste) are by-products of the associated increase in affluence that usually accompanies urbanization. These emissions are particularly worrisome when they exceed the earth's assimilative capacity. In a fast-approaching world with 9 billion people, 70 per cent[3] of whom are expected to live in urban areas by 2050, cities must be efficient, well managed and need to protect much better their most vulnerable populations. They also need to emit far less GHGs.

A large share of global greenhouse gas emissions is attributable to cities.[4] The International Energy Agency (IEA) estimates that urban areas currently account for more than 71 per cent of energy-related global greenhouse gases and this is expected to rise to 76 per cent by 2030,[5] making energy-related emissions the largest single source of GHG emissions from a production-based perspective (i.e. allocating emissions to the places where they are generated). Taking a consumption-oriented perspective (where emissions are allocated to the persons whose consumption caused the emissions), total GHG emissions rates would exceed this when the emissions associated with products consumed by urban residents are included, e.g. agriculture, forestry and commodities. Cities highlight the overlapping challenges of sustainable development, climate change mitigation and urban resilience. Concentrations of people and economic activity generate knowledge, social transformation, innovations and new technologies. They can also concentrate risk if not properly managed. Cities have the unique ability to respond to a global issue such as climate change at a local, more visceral level; they usually offer more immediate and effective communication between the public and the decision makers. Cities are credible laboratories of social change, with sufficient scale to bring about meaningful changes. Potential co-benefits of mitigation and adaptation are largest in cities.

City administrations and their citizens will be tasked with achieving the largest share of GHG emissions reductions. Using available GHG emissions data, this paper presents a possible path forward: clearly measure and communicate what is happening; tackle the largest issues first; and get help from citizens, other cities and national governments. Cities will likely address the challenge of GHG mitigation in the same pragmatic manner they have approached other issues such as solid waste management, water supply and, hopefully, better services to and inclusion of the urban poor.

II. GHG EMISSIONS: ASSIGNING RESPONSIBILITY

When it comes to the causes of climate change, statements have been made suggesting that up to 80 per cent of the world's anthropogenic greenhouse gas emissions are attributable to cities.[6] In contrast, arguments have been made against blaming cities for climate change based on observations such as: most emissions can occur outside the specific legislative boundary of cities, e.g. for electricity generation; and

1. World Bank (2009a), *World Development Report 2010: Development and Climate Change*, The World Bank, Washington DC, 417 pages.

2. World Bank (2008), *World Development Report 2009: Reshaping Economic Geography*, The World Bank, Washington DC, 383 pages.

3. United Nations Population Division (2009), "World urbanization prospects: the 2009 revision", accessed October 2010 at http://esa.un.org/unpd/wup/index.htm.

4. The world's 50 largest cities, for example, generate 2,606 MtCO2e per year, which, if a country, would constitute the world's third largest emitter. See World Bank (2010 forthcoming), *Cities and Climate Change: an Urgent Agenda*, The World Bank, Washington DC.

5. International Energy Agency (IEA) (2008), *World Energy Outlook 2008*, IEA, Paris, 569 pages.

6. These are summarized in Box 1 in Satterthwaite, David (2008), "Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions", *Environment and Urbanization* Vol 20, No 2, October, pages 539–549.

that urban living is more environmentally efficient than suburban and rural living at similar levels of affluence.[7] The conflict between these two perspectives represents the difference between production-based and consumption-based GHG attribution; that is, whether emissions are the "responsibility" of those who directly produce them or those whose consumption drives their production. Accordingly, in order to assess the level of climate change "responsibility" that should be assigned to cities, it is important to consider the fundamental role of the modern city in a global context, namely that cities are hubs of innovation, culture and economies that depend on a constant flow of resources, ideas, money and people. Cities are not self-sufficient entities and the impact of their activities extends far beyond their legislative boundaries. Cities are the most complex system created by humankind.

Many rural activities serve urban customers with their higher purchasing power, e.g. agriculture and forestry products and primary resource extraction such as minerals and hydrocarbons. Many high-emitting industries located outside cities, such as electricity generation from fossil fuels, would not exist were it not for urban residents. Therefore, emissions from these rural sources cannot be considered in isolation: from a consumption-oriented perspective, they are the responsibility of the cities they serve. A more accurate view would be that GHG emissions are the by-product of typical lifestyles of more affluent citizens, most of whom live in urban areas. In some OECD countries, a few affluent people are able to live in a more rural setting; however most of their wealth and lifestyle, e.g. automobiles, health care, travel, is linked to cities.

Consider the sheer magnitude of some larger world cities. Shanghai's population and greenhouse gas emissions would place it in the world's "top 40" if it were a separate country. In terms of economic significance, Tokyo and New York both have GDPs greater than Canada's.[8] Based on GHG emissions per GDP, citizens of Tokyo are 5.6 times more efficient than Canadians.[9] Combined, all member cities of the C40[10] represent 291 million people, at least 1,747 megatonnes of greenhouse gas emissions and more than US$ 10.8 trillion (PPP) total GDP,[11] placing the combined 40 cities among the top four countries in the world for each category (Table 1).

Chinese cities are atypical in that, generally, their GHG emissions are, on average, much higher than per capita national averages. For example, Shanghai's emissions are 12.6 tCO2e[12] per capita, while national emissions are 3.4 tCO2e per capita. This reflects the high reliance on fossil fuels for electricity production, a significant industrial base within many cities and a relatively poor and large rural population, and hence a lower average per capita value for national emissions. In Amman, Jordan, the majority of the 3.25 tCO2e per capita emissions are from fossil fuel combustion for electricity and in-city ground transportation.

For comparative purposes, Table 2 includes national as well as city-based GHG emissions per capita as reported by the Intergovernmental Panel on Climate Change (IPCC). Variations in these values derive from mainly production-based inventories for countries and production- and consumption-based values for cities. Values can vary markedly for the same resident of a city or country depending on whether these are production- or consumption-based, yet both are still accurate. For any city-based figure, clarity is needed on what is included in its greenhouse gas emissions inventory. Table 2's utility will increase as more values are

7. Including, for example, Satterthwaite (2008), see reference 6; also Dodman, David (2009), "Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories", *Environment and Urbanization* Vol 21, No 1, April, pages 185–201.

8. Hawksworth, John, Thomas Hoehn and Anmol Tiwari (2009), "Which are the largest city economies in the world and how might this change by 2025?", in Price Waterhouse Coopers (PwC), *UK Economic Outlook November 2009*, London, pages 20–34.

9. Calculated using GDP data from Hawksworth et al. (2009), see reference 8, and GHG data from Table 2. Canada's GHG emissions are production based, in line with IPCC reporting standards for countries. Tokyo's GHG emissions are production based for fossil fuel combustion and industrial processes, and consumption based for electricity and waste.

10. C40 is a group of large cities committed to tackling climate change; see http://www.c40cities.org/.

11. Calculated using GDP data from Hawksworth et al. (2009), see reference 8 (conservatively scaled by population with national data for cities not

TABLE 1
Rank of C40 member cities relative to the world's top nations in terms of population, GHG emissions and GDP

Population (millions)	GHG emissions (MtCO2e)	GDP (billion $ PPP)
(1) China: 1,191.8	(1) USA: 7,107.2	(1) USA: 14,202
(2) India: 915.7	(2) China: 4,057.6	(2) **C40 cities: 10,875**
(3) USA: 301.3	(3) Russian Federation: 2,192.8	(3) China: 7,903
(4) **C40 cities: 291.0**	(4) **C40 cities: 1,747.2**	(4) Japan: 4,354
(5) Indonesia: 190.0	(5) Japan: 1,374.3	(5) India: 3,388

SOURCE: GDP calculated using data from Hawksworth, John, Thomas Hoehn and Anmol Tiwari (2009), "Which are the largest city economies in the world and how might this change by 2025?", in Price Waterhouse Coopers (PwC), *UK Economic Outlook November 2009*, London, pages 20–34 (conservatively scaled by population with national data for cities not included in Hawksworth et al.). GHG emissions calculated using data from Table 2 and United Nations Framework Convention on Climate Change (UNFCCC) (2005), "Sixth compilation and synthesis of initial national communications from Parties not included in Annex I to the Convention", United Nations Office at Geneva, Geneva, 20 pages; also United Nations Framework Convention on Climate Change (UNFCCC) (2009), "National greenhouse gas inventory data for the period 1990–2007", United Nations Office at Geneva, Geneva, 27 pages. Population figures for nations are from the World Bank (2009), *World Development Report 2010: Development and Climate Change*, The World Bank, Washington DC, 417 pages, and for cities from C40 Cities: Climate Leadership Group (2010), "C40 cities: participating cities", accessed October 2010 at http://www.c40cities.org/cities.

obtained and aspects of inventories better clarified. This is particularly the case where efforts are made to include upstream emissions or embodied emissions associated with extraction, production and transport of products or services used by city residents (what are termed Scope 3 emissions, as discussed in more detail later).

Rotterdam's per capita value of 29.8 tCO2e versus 12.67 tCO2e for the Netherlands reflects the large impact of the city's port in attracting industry, as well as fuelling of ships. This is similar to cities with busy airports and highlights the need to view the city-based GHG emissions cautiously and holistically. Local anomalies can have a disproportionate impact. However, the utility of city-based emissions is still powerful for planning and policy purposes. New York and Denver provide a useful comparison. Average emissions for New York residents are half those for Denver, 10.5 tCO2e versus 21.5 tCO2e, and this is mainly attributable to New York's greater density and much lower reliance on the automobile for commuting. Denver also benefits from a more thorough review of emissions: if the embodied emissions from Scope 3 aspects such as food and concrete are included, emissions rise to 25.3 tCO2e per capita.(13)

Toronto and its place within Canada is illustrative. In Copenhagen in 2009, a coalition of environmental groups presented Canada with an unprecedented third consecutive "Fossil of the Year" award. Canada's annual per capita production-based GHG emissions are 22.65 tCO2e, among the highest in the world and a 26 per cent increase since 1990, rather than the 6 per cent reduction agreed to in the Kyoto protocol. More than 80 per cent of Canada is urbanized,(14) hence the majority of GHG emissions, if allocated per person, would be apportioned to urban residents.

Figure 1 provides disaggregated per capita emissions for various Canadians. All are accurate, yet these averages vary from a low of 6.4

included in Hawksworth et al.). GHG emissions calculated using data from Table 2 and United Nations Framework Convention on Climate Change (UNFCCC) (2005), "Sixth compilation and synthesis of initial national communications from Parties not included in Annex I to the Convention", United Nations Office at Geneva, Geneva, 20 pages; also United Nations Framework Convention on Climate Change (UNFCCC) (2009), "National greenhouse gas inventory data for the period 1990–2007", United Nations Office at Geneva, Geneva, 27 pages. Population figures for nations are from the World Bank (2009a), see reference 1, and for cities from C40 Cities: Climate Leadership Group (2010), "C40 cities: participating cities", accessed October 2010 at http://www.c40cities.org/cities.

12. Figures for tCO2e include not only carbon dioxide (the main greenhouse gas) but also other greenhouse gas emissions, but with their contribution to global warming converted to the amount of carbon dioxide that would have made the same contribution to global warming.

TABLE 2
GHG baselines for cities and their respective countries*

Country/city	GHG emissions (tCO2e/capita)		
Argentina	**7.64**	2000	
Buenos Aires	3.83		(1)
Avellaneda	6.53		(1)
Australia	**25.75**	2007	
Sydney	20.3	2006	(2)
Bangladesh	0.37	1994	
Chittagong	0.10		(1)
Dhaka	0.63		(1)
Khulna	0.09		(1)
Rajshahi	0.08		(1)
Belgium	**12.36**	2007	
Brussels	**7.5**	2005	(3)
Bhutan	**2.52**	1994	
Phuentsholing	0.64		(1)
Thimphu	0.33		(1)
Brazil	**4.16**	1994	
Goiânia	0.99		(1)
Pôrto Alegre	1.48		(1)
Rio de Janeiro	**2.1**	1998	(3 i)
São Paulo	**1.4**	2000	(3 i)
Canada	**22.65**	2007	
Calgary	**17.7**	2003	(3)
Toronto (City of Toronto)	9.5	2004	(4)
Toronto (Metropolitan Area)	**11.6**	2005	(5 i)
Vancouver	4.9	2006	(6)
China	**3.40**	1994	
Beijing	**10.1**	2006	(3 i)
Shanghai	**11.7**	2006	(3 i)
Tianjin	**11.1**	2006	(3 i)
Chongqing	3.7	2006	(7)
Czech Republic	**14.59**	2007	
Prague	**9.4**	2005	(5 i)
Finland	**14.81**	2007	
Helsinki	**7.0**	2005	(3)
France	**8.68**	2007	
Paris	**5.2**	2005	(3)
Germany	**11.62**	2007	
Frankfurt	**13.7**	2005	(3)
Hamburg	**9.7**	2005	(3)
Stuttgart	**16.0**	2005	(3)
Greece	**11.78**	2007	
Athens	**10.4**	2005	(3)
India	**1.33**	1994	
Ahmedabad	1.20		(1)
Bangalore	0.82		(1)
Chennai	0.91		(1)
Coimbatore	1.37		(1)
Delhi	1.50	2000	(8)
Faridabad	1.58		(1)
Gurgaon	2.13		(1)
Hyderabad	1.08		(1)
Jaipur	1.63		(1)
Kolkata	1.10	2000	(8)
Ludhiana	1.49		(1)
Mysore	0.72		(1)
Patna	0.83		(1)
Pune	1.31		(1)
Surat	0.91		(1)
Udaipur	0.76		(1)
Italy	**9.31**	2007	
Bologna (Province)	**11.1**	2005	(3)
Naples (Province)	**4.0**	2005	(3)
Turin	**9.7**	2005	(3)
Veneto (Province)	**10.0**	2005	(3)
Japan	**10.76**	2007	
Tokyo	**4.89**	2006	(3 i)
Jordan	**4.04**	2000	
Amman	**3.25**	2008	(9 i)
Mexico	**5.53**	2002	
Mexico City (City)	4.25	2007	(10)
Mexico City (Metropolitan Area)	2.84	2007	(10)
Nepal	**1.48**	1994	
Kathmandu	0.12		(1)
Lalitpur	0.33		(1)
Pokhara	0.35		(1)
Norway	**11.69**	2007	
Oslo	**3.5**	2005	(3)
Portugal	**7.71**	2007	
Porto	**7.3**	2005	(3)
Republic of Korea	**11.46**	2001	
Seoul	4.1	2006	(3)
Singapore	**7.86**	1994	
Slovenia	**10.27**	2007	
Ljubljana	**9.5**	2005	(3)

TABLE 2 (CONTINUED)

Country/city	GHG emissions (tCO2e/capita)		Country/city	GHG emissions (tCO2e/capita)	
South Africa	**9.92**	1994	**London (Greater London Area)**	**9.6**	2003 (5 i)
Cape Town	**11.6**	2005 (5 i)	**Glasgow**	**8.8**	2004 (3)
Spain	**9.86**	2007	**USA**	**23.59**	2007
Barcelona	**4.2**	2006 (5 i)	**Austin**	**15.57**	2005 (3)
Madrid	**6.9**	2005 (3)	Baltimore	14.4	2007 (11)
			Boston	13.3	(12)
Sri Lanka	**1.61**	1995	Chicago	12.0	2000 (13)
Colombo	1.54	(1)	Dallas	15.2	(12)
Kandy	1.27	(1)	**Denver**	**21.5**	2005 (5 i) (†)
Kurunegala	9.63	(1)	Houston	14.1	(12)
Matale	2.41	(1)	Philadelphia	11.1	(12)
Sweden	**7.15**	2007	Juneau	14.37	2007 (14)
Stockholm	**3.6**	2005 (3)	**Los Angeles**	**13.0**	**2000 (5 i)**
			Menlo Park	16.37	2005 (15)
Switzerland	**6.79**	2007	Miami	11.9	(12)
Geneva	**7.8**	2005 (5 i)	**Minneapolis**	**18.34**	2005 (3)
The Netherlands	**12.67**	2007	**New York City**	**10.5**	2005 (5 i)
Rotterdam	**29.8**	2005 (3)	**Portland, OR**	**12.41**	2005 (3)
			San Diego	11.4	(12)
Thailand	**3.76**	1994	San Francisco	10.1	(12)
Bangkok	**10.7**	2005 (5 i)	**Seattle**	**13.68**	2005 (3)
UK	**10.50**	2007	Washington DC	19.70	2005 (16)

NOTE: *Values in bold are peer reviewed and considered comparable (city-to-city and country-to-country). Inventory year, source and inventory content are indicated with footnotes.

(i) Value includes emissions from aviation and marine sources.
(†) Value for Denver is available that includes embodied emissions in food and cement: 25.3 tCO2e/capita. See Ramaswami, A, T Hillman, B Janson, M Reiner and G Thomas (2008), "A demand-centred, hybrid lifecycle methodology for city-scale greenhouse gas inventories", *Environmental Science and Technology* Vol 42, No 17, pages 6455–6461.
(1) Values provided by ICLEI.
(2) City of Sydney (2008), "Local government area greenhouse gas emissions", accessed March 2010 at http://cityofsydney.nsw.gov.au/Environment/GreenhouseAndAirQuality/CurrentStatus/GreenhouseGasEmissions.asp.
(3) Kennedy C, A Ramaswami, S Carney and S Dhakal (2009), "Greenhouse gas emission baselines for global cities and metropolitan regions", Proceedings of the 5th Urban Research Symposium, Marseille, France, 28–30 June 2009.
(4) City of Toronto (2007), "Greenhouse gases and air pollutants in the city of Toronto, 2004", accessed March 2010 at http://www.toronto.ca/teo/pdf/ghg-aq-inventory-june2007.pdf.
(5) Kennedy C, J Steinberger, B Gasson, Y Hansen, T Hillman, M Havranek, D Pataki, A Phdungsilp, A Ramaswami and G Villalba Mendez (2009), "Greenhouse gas emissions from global cities", *Environmental Science and Technology* Vol 43, pages 7297–7302.
(6) City of Vancouver (2007), "Climate protection progress report", accessed March 2010 at http://vancouver.ca/sustainability/documents/Progress2007.pdf.
(7) Dhakal, S (2009), "Urban energy use and carbon emissions from cities in China and policy implications", *Energy Policy* Vol 37, pages 4208–4219.
(8) Mitra, A P, C Sharma and M A Y Ajero (2003), "Energy and emissions in south Asian mega-cities: study on Kolkata, Delhi and Manila", Proceedings of IGES/APN International Workshop on Policy Integration Towards Sustainable Energy Use for Cities in Asia, Honolulu, Hawaii, 4–5 February 2003.
(9) Sugar, L (2010), "Amman's greenhouse gas emissions", The World Bank, Washington DC, 14 pages.

TABLE 2 (CONTINUED)

(10) Mexico City Government (2009), "City case studies on climate change strategies and use of carbon incentives", Paper presented at the Symposium for Cities, Climate Change and Carbon Finance: Elements for a City-led Agenda on the Road to Copenhagen, Barcelona, Spain, 26 May 2009.
(11) City of Baltimore (2008), "Greenhouse gas emissions inventory for Baltimore city", accessed March 2010 at http://www.ci.baltimore.md.us/government/planning/sustainability/downloads/presentations/102008GHG_Emissions_Inventory_Presentation.pdf.
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13. Ramaswami, A, T Hillman, B Janson, M Reiner and G Thomas (2008), "A demand-centred, hybrid lifecycle methodology for city-scale greenhouse gas inventories", *Environmental Science and Technology* Vol 42, No 17, pages 6455–6461.

14. Statistics Canada (2006), "Population by urban and rural", accessed March 2010 at http://www40.statcan.gc.ca/l01/cst01/demo62a-eng.htm?sdi=urban.

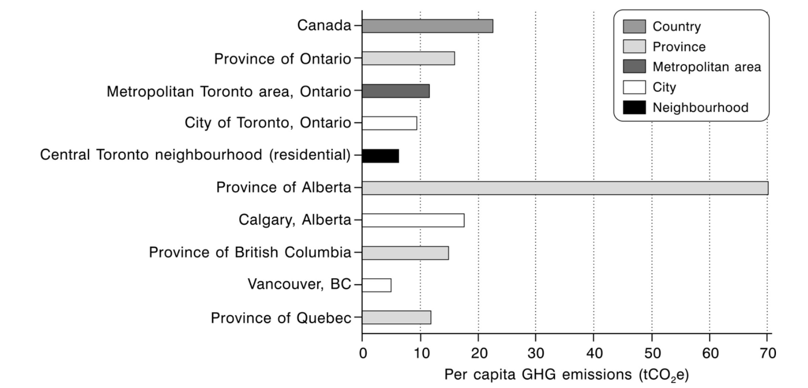

FIGURE 1
Disaggregated per capita emissions for various Canadians*

NOTE: *National and provincial emissions are production based; city emissions are production based for fossil fuel combustion and industrial processes, and consumption based for electricity and waste; neighbourhood emissions are production based for transportation, and consumption based for household energy.

SOURCE: National and provincial data from Environment Canada (2010), "Canada's greenhouse gas inventory: national/provincial/territorial tables", accessed October 2010 at http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1. Metropolitan Toronto data from Kennedy, C, J Steinberger, B Gasson, Y Hansen, T Hillman, M Havranek, D Pataki, A Phdungsilp, A Ramaswami and G Villalba Mendez (2009), "Greenhouse gas emissions from global cities", *Environmental Science and Technology* Vol 43, No 19, October, pages 7297–7302; also City of Toronto (2007), "Greenhouse gases and air pollutants in the city of Toronto, 2004", accessed March 2010 at http://www.toronto.ca/teo/pdf/ghg-aq-inventory-june2007.pdf. Neighbourhood data from VandeWeghe, Jared R and Christopher Kennedy (2007), "A spatial analysis of residential greenhouse gas emissions in the Toronto census metropolitan area", *Journal of Industrial Ecology* Vol 11, No 2, pages 133–144.

tCO2e per capita in a central neighbourhood in Toronto to a high of 70.1 tCO2e per capita for an Albertan. There are variations within provinces and cities, and the same person can have different emissions depending on the geographical area used. For example, the same Toronto resident's per capita emissions are 6.42 tCO2e for their household emissions, 9.5 tCO2e for citywide emissions, 11.6 tCO2e for the Greater Toronto metropolitan area, 16.0 tCO2e as a resident of the province of Ontario and 22.65 tCO2e as an average Canadian.

Per capita estimates of emissions represent not only an individual's lifestyle choices but also the nature of the infrastructure and the structure of the economy in the geographical region. In most OECD countries, city per capita GHG emissions are lower than their national inventories, reflecting the general lack of resource development and heavy industry in cities. However, cities still generally follow regional and national trends, specifically with regard to electricity production and consumption, urban form and building practices, e.g. Calgary and Alberta.

The provinces of British Columbia, Quebec and Ontario, with a higher reliance on hydro-electricity and an absence of petroleum-based development, have relatively lower emissions. Their relatively aggressive greenhouse gas mitigation targets often reflect this while the national government, with one eye on hydrocarbon-rich regions of the country and the other on the trading relationship with the US, espouses a much more conservative mitigation strategy. Similarly, Canada's larger cities, with a denser public transport network, have disproportionately lower per capita GHG emissions. The complexities associated with these emissions and associated economies are significant; for example Alberta, with its oil sands, is a significant net contributor to Canada's federal financial equalization payments (largely funded by petroleum royalties), while Quebec and now Ontario are net benefactors.

Emissions also vary significantly at the neighbourhood level, as shown in a study by VandeWeghe and Kennedy of consumption-based household emissions and production-based transport emissions by census tract for the city of Toronto.(15) On average, residents in the city core produced 6.42 tCO2e per capita compared to 7.74 tCO2e per capita for residents in the surrounding suburbs. However, there were pockets within the city core that produced emissions as high as those in the suburbs; these census tracts represented wealthy neighbourhoods, characterized by high automobile use and older, inefficient homes. The lowest emissions were 1.31 tCO2e per capita for a dense inner-city neighbourhood with good access to public transportation. The highest emissions were 13.02 tCO2e per capita in a "sprawling" distant suburb.

A close examination of the GHG attribution by census tract reveals interesting correlations between per capita GHG emissions, urban form and service access. Photo 1 shows satellite imagery of three Toronto census tracts: the tract with the lowest per capita emissions, a tract with the average per capita emissions and the tract with the highest per capita emissions. The neighbourhood with the lowest emissions per capita is a high-density apartment complex within walking distance of a shopping centre and public transit. The average emissions per capita neighbourhood consists of high-density single family homes close to the downtown core and with access to public transit. The highest emissions per capita neighbourhood is located in the suburbs, consisting of large, low-density single family homes, distant from commercial activity.

15. VandeWeghe, Jared R and Christopher Kennedy (2007), "A spatial analysis of residential greenhouse gas emissions in the Toronto census metropolitan area", *Journal of Industrial Ecology* Vol 11, No 2, pages 133–144.

PHOTO 1A
East York. Total 1.31 tCO2e per capita (residential only)

PHOTO 1B
Etobicoke. Total 6.62 tCO2e per capita (residential only)

PHOTO 1C
Whitby. Total 13.02 tCO2e per capita (residential only)

Satellite imagery of three Toronto census tracts*

NOTE: *East York, with the lowest GHG emissions per capita, shows high-rise apartment buildings; Etobicoke, with average GHG emissions per capita, shows dense, single-family homes; and Whitby, with the highest GHG emissions per capita, shows a low-density suburban development.

SOURCE: VandeWeghe, Jared R and Christopher Kennedy (2007), "A spatial analysis of residential greenhouse gas emissions in the Toronto census metropolitan area", *Journal of Industrial Ecology* Vol 11, No 2, pages 133–144. Images © Google Earth, 2010.

This heterogeneity of per capita emissions is not unique to Canada. Whether the comparison is made city-to-city, region-to-region or country-to-country, large disparities are evident everywhere. These disparities are similar to per capita solid waste generation (Figure 2). For both GHG emissions and solid waste, which are most closely correlated to affluence, the world's poorest regions generate very little.

Canada's relatively high per capita production-based emissions reflect that it is the only net exporter of carbon dioxide emissions within the G7 countries.[16] Davis and Caldeira, using the latest available data, found that in 2004, 23 per cent of global production-based carbon dioxide emissions were traded internationally, with consumption-based net imports for many European nations greater than four tCO2e per capita and 2.4 tCO2e per capita for the US.[17] The challenges of comparing city, provincial and national emissions are apparent when apportioning emissions from

16. In 2004, Canada's GHG emissions embodied in exports were 184 MtCO2e and in imports 160 MtCO2e, for a net export of 0.75 tCO2e per capita. See Davis, Steven J and Ken Caldeira (2010), "Consumption-based accounting of CO2 emissions", *Proceedings of the National Academy of Sciences of the United States of America* Vol 107, No 12, pages 5687–5692.

17. See reference 16, Davis and Caldeira (2010).

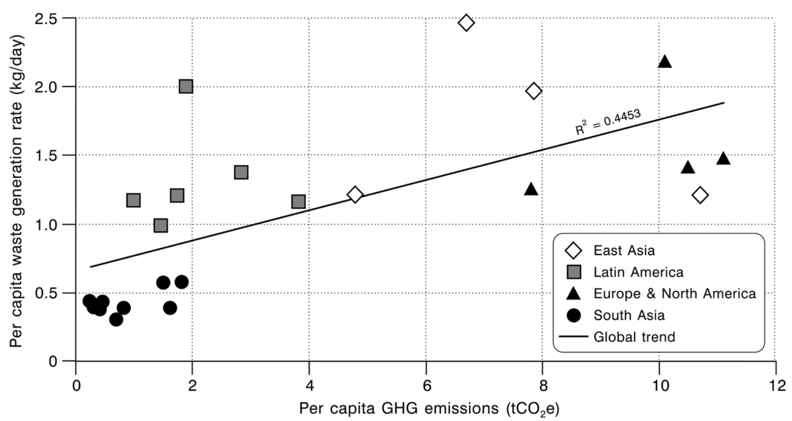

FIGURE 2
Per capita GHG emissions (tCO2e) and waste generation rate (t/day) for selected cities, indicated by region

SOURCE: Waste data from World Bank (2010 forthcoming), *What a Waste: Waste Management around the World*, The World Bank, Washington DC. GHG emissions data from World Bank (2010 forthcoming), *Cities and Climate Change: an Urgent Agenda*, The World Bank, Washington DC; also see Table 4.

exported products, where arguably everyone in the exporting country benefits, or emissions associated with national activities such as the military, international tourism and land use changes. Furthermore, distinguishing between apportioning emissions based on consumption or production is important so as to avoid double-counting in emissions inventories.

III. CITIES ARE MAJOR PLAYERS IN CLIMATE CHANGE MITIGATION

Global trends and cultural shifts now arise exclusively through cities. Globalization is anchored through the growing connectivity of about 75 "global cities". Through their economic heft and trend-setting nature, these "country-lites" act as portals in determining much of our collective civilization.

By their nature, as national governments deal with more intractable geo-political issues, cities are often able to better cooperate with each other than their host countries. Cities often express the aspirations of their citizens more succinctly and more quickly than higher levels of government, and when these rising voices are credibly articulated, their global impact is considerable. The global response to climate change is illustrative. In the US, for example, 1,017 cities have signed up to meet or exceed Kyoto Protocol targets to reduce GHG emissions,(18) even though the national government refused to sign the protocol.

Because of their proximity to the public and the focus on providing day-to-day services, cities tend to be more pragmatic than senior levels of

18. US Mayors (2009), "US conference of mayors – climate protection agreement", accessed March 2010 at http://usmayors.org/climateprotection/agreement.htm.

government. National governments may set the rules of the game but it is cities that are the athletes. For the athletes to "play the game", not only is it crucial that they know the rules but also that their voices and those they represent are incorporated during the formulation of the rules.

Climate change will require city administrations to develop more robust partnerships with their constituencies, especially in low- and middle-income countries. The public needs to be an integral part of future responses to climate change, and trust needs to be strengthened before specific actions are identified. One way to achieve this is to regularly supply the public with credible standardized information that encourages active debate and outlines the need and methods for concrete actions.

Key urban policy initiatives can play an important role in addressing climate change mitigation and adaptation. A study of competitive cities and climate change emphasizes that policy complementarities across urban sectors are essential for enhancing policy effectiveness. For example, "*…congestion fees for driving during peak hours worked well in London because they were combined with improvements in management of the road network and substantial enhancements in bus service.*"[19]

Figure 3 highlights the particular impact of policy changes on carbon dioxide emissions per capita in Sweden and Germany from 1967 to 2005 along with a decline in industrial production. Efforts undertaken by and within cities were largely responsible for the majority of the dramatic GHG reductions in these two countries. Urban infrastructure and policies influence lifestyle choices, which in turn impact on urban emissions. For example, a lack of efficient public transit and low parking prices encourage greater car use. City governments have the ability to influence lifestyle choices and reduce greenhouse gas emissions. Table 3 provides an array of policy tools that are being implemented by cities. Some examples of municipal policies leading to reductions in emissions include congestion pricing (Singapore and Stockholm), dense and integrated land use (Barcelona and São Paulo), and provision of good public transit (Zurich and Curitiba).

In cities, there is the potential to capitalize on the co-benefits of mitigation, adaptation and improved access to services. Cities with excellent services are resilient cities: advanced drainage systems can alleviate flooding during intense storms; robust healthcare services are equipped to respond in emergency situations; warning systems and transportation infrastructure allow citizens to evacuate in response to risk.

19. Kamal-Chaoui, Lamia and Alexis Robert (editors) (2009), "Competitive cities and climate change", OECD Regional Development Working Paper No 2, OECD Publishing, page 12.

IV. ACTION BEGINS WITH A GREENHOUSE GAS INVENTORY

The mitigation process to reduce GHG emissions should begin with a good understanding of emissions sources. This is accomplished with a clear and comprehensive greenhouse gas inventory. Greenhouse gas inventories for local jurisdictions identify emissions by source and report them in per capita terms. By identifying sectors with high levels of emissions, cities can determine where best to direct mitigation efforts. Regular updating is also needed to monitor the impact of policy initiatives.

Even with the complexity of the systems and dynamics found in cities, greenhouse gas emissions reflect well the multi-faceted nature of urban activity. GHGs are waste products expelled into the atmosphere as a result of various activities. The level of economic and social activity, as well as the systems and structures that enable activities, determine the

TABLE 3
Policy tools for local-level action on climate change

Policy goals	Policy tools	Policy sector	Purpose	Mode of governance	Complementary with policy tools that:
Reduce trip lengths	Restructure land value tax to increase value of land closer to urban core, jobs or services	Land use zoning	Mitigation	Regulatory	Increase mass transit use*
	Mixed use zoning to shorten trip distances	Land use zoning	Mitigation	Regulatory	Discourage vehicle use;* support non-motorized means of travel
Increase mass transit use	Transit-oriented development zones	Land use zoning	Mitigation	Regulatory	Increase mass transit use;* discourage vehicle use*
	Restructure land value tax to increase value of land served by public transportation	Land use zoning	Mitigation	Regulatory	Increase mass transit use*
	Tax incentives to developers near public transportation	Land use zoning	Mitigation	Regulatory	Increase mass transit use*
	Improve quality of public transportation	Transportation	Mitigation	Service provision	Discourage vehicle use*
	Provide linkages with multiple modes of travel	Transportation	Mitigation	Service provision	Discourage vehicle use;* support non-motorized means of travel*
	Expand mass transit service	Transportation	Mitigation	Service provision	Discourage vehicle use*
	Employee transport plans	Transportation	Mitigation	Facilitative	Improve quality of public transportation; provide linkages with multiple modes of travel; expand mass transit service
Discourage vehicle use	Traffic calming to discourage driving	Land use zoning	Mitigation	Regulatory/ service provision	Improve quality of public transportation; provide linkages with multiple modes of travel; expand mass transit service
	Driving and parking restrictions in certain zones	Transportation	Mitigation	Regulatory	Improve quality of public transportation; provide linkages with multiple modes of travel; expand mass transit service

TABLE 3 (CONTINUED)

Policy goals	Policy tools	Policy sector	Purpose	Mode of governance	Complementary with policy tools that:
Support non-motorized means of travel	Traffic calming and increase bike lanes	Transportation	Mitigation	Regulatory/ service provision	Discourage vehicle use*
Increase vehicle efficiency and alternative fuels use	Special parking privileges for alternative fuel or hybrid vehicles	Transportation	Mitigation	Regulatory	Driving and parking restrictions in certain zones
	Purchase of fuel efficient, hybrid or alternative fuel vehicles for city fleet	Transportation	Mitigation	Self-governance	—
Increase building energy efficiency	Zoning regulation to promote multi-family and connected residential housing	Land use zoning	Mitigation	Regulatory	Increase attractiveness of higher-density developments through policy tools that: increase neighbourhood open space; improve quality of public transportation; provide linkages with multiple modes of travel; expand mass transit service; tree-planting programmes
	Energy efficiency requirements in building codes	Building	Mitigation	Regulatory	Coordination of public–private retrofitting programmes; stringent enforcement policies; national building codes
	Coordination of public–private retrofitting programmes	Building	Mitigation	Service provision	Energy efficiency requirements in building codes
Increase local share of renewable and captured energy generation	Building codes requiring a minimum share of renewable energy	Building	Mitigation	Regulatory	Technical support to developers and property owners
	District heating and cooling projects	Building	Mitigation	Regulatory/ service provision	Remove regulatory barriers to requiring connection to district heating/cooling system
	Waste-to-energy programmes	Waste	Mitigation	Service provision	Strictly regulate incinerator emissions; remove recyclables from waste stream

TABLE 3 (CONTINUED)

Policy goals	Policy tools	Policy sector	Purpose	Mode of governance	Complementary with policy tools that:
Reduce vulnerability to flooding and increased storm events	Zoning regulation to create more open space	Land use zoning	Adaptation	Regulatory	Zoning regulation to promote multi-family and connected residential housing
	Retrofitting and improvements to mass transit systems to reduce potential damage from flooding	Transportation	Adaptation	Service provision	Improve quality of public transportation; provide linkages with multiple modes of travel; expand mass transit service
	Designation of open space as buffer zones for flooding	Natural resources	Adaptation	Regulatory	Zoning regulation to create more open space; zoning regulation to promote multi-family and connected residential housing
	Building codes requiring minimum ground clearance	Building	Adaptation	Regulatory	Designation of open space as buffer zones for flooding
Reduce urban heat-island effects and vulnerability to extreme heat	Retrofitting and improvements to mass transit systems to reduce potential damage from extreme temperatures	Transportation	Adaptation	Service provision	Improve quality of public transportation; provide linkages with multiple modes of travel; expand mass transit service
	Tree-planting programmes	Natural resources	Mitigation and adaptation	Self-governance	Increase attractiveness of higher-density developments
	Building codes requiring design materials that reduce heat-island effects	Building	Adaptation	Regulatory	Energy efficiency requirements in building codes
	Building codes requiring "green roofs" with vegetation or white surfaces	Building	Mitigation and adaptation	Regulatory	Energy efficiency requirements in building codes

NOTE: *Denotes all policy tools listed under a policy goal.

SOURCE: Kamal-Chaoui, Lamia and Alexis Robert (editors) (2009), "Competitive cities and climate change", OECD Regional Development Working Paper No 2, OECD Publishing, 172 pages.

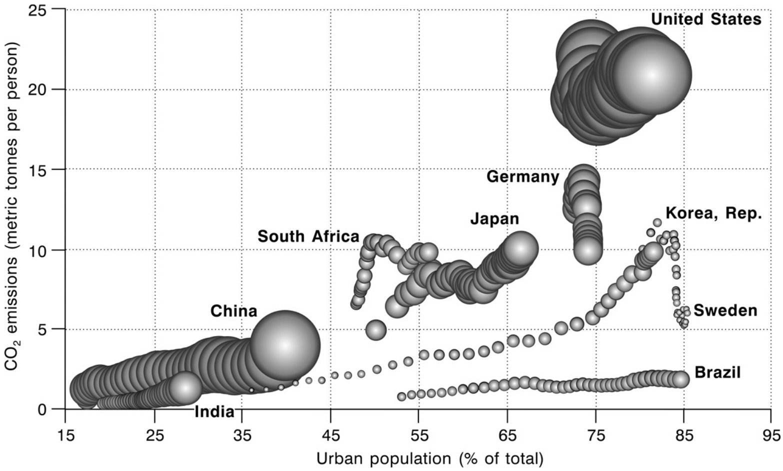

FIGURE 3
Carbon dioxide emissions (tCO2) per capita, 1967–2005

NOTE: The bubble size corresponds to total carbon dioxide emissions (kilotonnes).

SOURCE: World Bank (2009), **The Little Green Data Book**, The World Bank, Washington DC, 232 pages.

amount of greenhouse gases produced. Therefore, GHG emissions provide a clear link between daily life and climate change.

Per capita estimates of urban GHG emissions largely reflect the nature and economic structure of their respective cities. For example, a city with heavy industry, high car usage and coal-generated electricity will have higher per capita emissions than a city with a knowledge-based industry, good public transit and electricity drawn from hydropower. More research is needed, but as Table 2 shows, the variations between cities may be as wide as within cities. Emissions are likely most closely correlated to affluence, and low neighbourhood-level emissions might offset the higher global emissions resulting from air travel or second homes.

Urban greenhouse gas inventories should follow a procedure similar to the IPCC methodology for national inventories. This will enable all city inventories to mesh with regional and national inventories. Since there is currently no mandated standard for urban greenhouse gas accounting, inventories vary depending on the data availability and the organization responsible for calculations.

The attribution of GHG emissions to cities reveals issues of inventory "scope". The World Resources Institute and World Business Council for Sustainable Development introduced the scope concept in relation to corporate or organizational inventories, dividing all emissions into three broad scopes. Scope 1 emissions are those from sources under the direct control of the organization, such as furnaces, factories or vehicles; Scope 2 emissions are from electricity consumed by the organization, although emissions are produced elsewhere; and Scope 3 emissions, also called upstream emissions or embodied emissions, are associated with extraction, production and transportation of products or services used by the organization. The scope concept of emissions attribution can also be applied to cities, giving them responsibility for emissions that are a consequence of their residents' activities, regardless of whether or not they occur inside the city boundary.

The international standard for determining greenhouse gas emissions for cities, presented at the 2009 Urban Research Symposium in Marseille[20] and summarized in Table 4, recommends that emissions are reported from four categories: energy (including emissions from electricity consumption, heating and industrial fuel use, ground transport, and aviation and marine transport); industrial processes and product use; AFOLU (agriculture, forestry and other land use change); and waste. There is also a suggestion to report emissions embodied in fuel, water, food and building materials as additional items.[21] Including Scope 3 emissions in eight US city case studies increases urban inventories by an average of 45 per cent.[22] The following reported items are recommended for inclusion: emissions produced in the geographical boundary of the city (Scope 1: production-based emissions); emissions released outside the geographical boundary of the city that enable energy, including electricity and district heat, to be consumed in the city (Scope 2: consumption-based emissions); and emissions from waste, aviation and marine transport and embodied in fuel, food, building materials and water used in the city (Scope 3: consumption-based emissions).

20. Proposed by Kennedy C, A Ramaswami, S Carney and S Dhakal (2009), "Greenhouse gas emission baselines for global cities and metropolitan regions", Proceedings of the 5th Urban Research Symposium, Marseille, France, 28–30 June 2009, and by UNEP/UN–HABITAT/World Bank (2010), "International standard for determining greenhouse gas emissions from cities", presented at the World Urban Forum, Rio de Janeiro, Brazil, 22–26 March 2010, accessible at http://siteresources.worldbank.org/INTUWM/Resources/GreenhouseGasStandard.pdf.

21. See reference 20, Kennedy et al. (2009).

22. This was demonstrated by Hillman, T and A Ramaswami (2009), "Greenhouse gas footprints and energy use benchmarks for eight US cities", submitted to *Environmental Science and Technology*.

TABLE 4
Summary of international standard for determining greenhouse gas emissions for cities, proposed by UNEP/UN–HABITAT/World Bank

Reported item	Scope*
ENERGY	
a) Stationary combustion	
Electricity	1,2,3
District energy and combined heat and power	1,2
Heating and industrial fuels	1
b) Mobile combustion	
Ground transportation	1
Aviation and marine	3
INDUSTRIAL PROCESSES	1
AGRICULTURE, FORESTRY AND LAND USE	1
WASTE	1,3
UPSTREAM EMISSIONS	
Energy	3
Water and wastewater	3
Building materials	3
Food	3

NOTE: *See text for explanation of "scope" concept.

SOURCE: UNEP/UN–HABITAT/World Bank (2010), "International standard for determining greenhouse gas emissions from cities", presented at the World Urban Forum, Rio de Janeiro, Brazil, 22–26 March 2010, also accessed October 2010 at http://siteresources.worldbank.org/INTUWM/Resources/GreenhouseGasStandard.pdf.

While data can be difficult to obtain, the reporting of upstream, consumption-based emissions provides the most comprehensive view of the greenhouse gas emissions arising from an urban system for decision makers. Upstream emissions may be used to inform systemic consequences of climate change actions. Some actions that reduce climate change in cities may increase emissions in rural areas; for example, exporting cement manufacturing to rural areas removes emissions from cities but increases emissions associated with transportation. The Scope 3 analysis of Denver[23] led to the adoption of green concrete policies, reducing upstream emissions in new construction projects. As cities create strategic plans for mitigation, it is important to consider these upstream impacts as they can provide indications of what is driving emissions.

23. See reference 13; also see reference 20 Kennedy et al. (2009).

Table 2 presents a list of currently assessed urban greenhouse gas baselines for about 100 cities, reported as values per capita, with a per capita inventory value for the corresponding country. The organization responsible for preparing each inventory is indicated. While the methodology and data available for each city may vary, Table 2 is an important starting point for future consistency in urban inventory reporting.

In looking at the inventories presented in Table 2, some important trends emerge: low- and middle-income countries tend to have lower per capita emissions than high-income countries; dense cities tend to have relatively lower per capita emissions (particularly those with good transportation systems); cities tend to have higher emissions if in a cold climate zone. The most important observation is that there is no single factor that can explain variations in per capita emissions across cities; they are agglomerations of a variety of physical, economic and social factors specific to their unique urban life. The details of each inventory and its ability to undergo peer review, however, are critical to the development and monitoring of an effective mitigation strategy.

The city of Toronto, for which some of the most comprehensive spatial data is now available, provides an important observation: in the total emissions per capita value for citywide (9.5 tCO2e) and metropolitan (11.6 tCO2e), residential contributions account for approximately 68 per cent and 57 per cent, respectively. The "low" and "high" neighbourhoods vary by as much as a factor of 10. This suggests that what you buy is important, but what type of housing and neighbourhood you live in is much more important.

V. EMPOWERING CHANGE THROUGH CITIES

Cities are the optimum scale for integrated policy development and action on climate change mitigation. With more than half the world now urbanized and the vast majority of the world's economy driven by cities, national and international policies are also urbanizing. As the example of Toronto and Canada highlights though, the development and implementation of policies for GHG mitigation requires complementary and differentiated efforts by all governments and increasing reliance on complementary individual choices within larger neighbourhoods and citywide developments. The experience with solid waste management and waste diversion from final disposal provides important lessons for GHG mitigation. Cities and countries that enacted complementary policies for waste management practices have had the most success at solid waste diversion, for example: local tipping fees; bans on products and materials, such as limiting packaging materials and banning organics from landfill; extended product responsibility; and clearly articulated local and national waste diversion targets. Reducing GHG emissions will be achieved through a similar suite of policies and actions, for example: local "emitting" fees and emissions trading systems such as there are now in place in Tokyo; local and national targets; extended product responsibility; and local provision of practical alternatives such as improved public transport, more energy-efficient homes and more low-carbon city forms. With both GHG emissions and solid waste, the disparities within and across cities are striking; the poor generate little but are often severely impacted.

In addition to financing, cities need new and powerful tools to mitigate GHG emissions. Credible, publicly available and consistent GHG inventories, which are nested within national inventories, are critical to drive municipal policies and actions. These tools are evolving, but as this paper highlights they are now sufficiently robust to be collected by all cities (at least for all those with more than one million inhabitants). The use of GHG inventories is only a small part of a city's responsibility in mitigating GHG emissions; however, it is an important pre-requisite to mobilizing personal contributions and urging complementary regional and national efforts. Assigning blame can be useful but is far less productive than establishing credible and differentiated action plans and carrying them out. Mitigating GHG emissions can start at an individual level and quickly scale up to national and international efforts.

Similar to programmes to reduce solid waste volumes that focused on waste generation both in and out of the home, since, in most cities, more than 60 per cent of the waste is generated outside of the home, GHG mitigation strategies will likely evolve along two complementary parallel tracks. The first – and largely led by individual cities – will focus on urban form, with a keen interest in housing type and on integrated transport systems. The second track will require cooperative efforts between cities and countries, and will encourage less carbon-intense electricity, greater efficiency for all products and activities, for example international air travel, and likely a particular focus on the poor in cities in low-income and many middle-income nations, who emit virtually no emissions yet, but will be most impacted.

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